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An Evaluation of the Frankfort Mandibular Plane Angle Bisector (FMAB) Wits Appraisal in the Assessment of Anteroposterior Jaw Relationships in Class II Individuals

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A thesis submitted in partial fulfillment of the requirements for the degree in Master of Clinical Science

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Abstract

The treatment of Class II malocclusions has long been a difficult and challenging task for orthodontists. It has been estimated that roughly one-third to one-half of clinical orthodontic practices consist of Class II malocclusions due to a dental discrepancy and/or a skeletal discrepancy between the maxilla and mandible. Thus, accurate diagnosis and treatment planning are of vital importance to practicing orthodontists. The purpose of this longitudinal study was to evaluate the reliability and validity of the Frankfort Mandibular Plane Angle Bisector (FMAB) reference plane in the assessment of anteroposterior discrepancies in a sample of Class II Division 1 individuals. Comparisons were made between the FMAB, ANB angle, and maxillo-mandibular Bisector (MMB) in both treated and control samples of Class II Division 1 patients.

The data was collected from pre-treatment (T0), immediate post-treatment (T1) and two year post-retention (T2) lateral cephalograms of 40 female and 36 male Class II Division 1 subjects. Patients were treated non-extraction with fixed orthodontic appliances in conjunction with cervical or straight pull headgears and Class II elastics. Cephalometric data were compared to an untreated control group of 15 female and 15 male Class II Division 1 subjects. The data was evaluated using independent samples t-tests and ANOVA statistical tests to determine statistical differences between groups ($p < 0.05$).

The FMAB was determined to be a highly reproducible reference plane which mimics the ANB angle in the changes seen with growth and treatment. The FMAB-Wits had a mildly higher correlation with the ANB angle than the MMB-Wits. A good correlation ($r > 0.80$) was found between the FMAB-Wits and MMB-Wits appraisal measurements in both the control and treatment groups for all time periods, indicating that the use of either of these measures may be indicated in cephalometric analysis.

Key Words: Class II Division 1 malocclusions, Wits Appraisal, Frankfort Mandibular Plane Bisector, Maxillomandibular Plane Bisector

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Introduction

The treatment of Class II malocclusions has long been a difficult and challenging task for orthodontists. Numerous studies have indicated that the prevalence of Class II malocclusions in the present population is much greater than the prevalence of Class II malocclusions a few hundred years ago.[1] One study examining 1700 children from age 9 to 18 years found that Class II malocclusions were present in 24% of the sample group.[2] Furthermore, the National Health and Nutrition Estimates Survey III[3], carried out in the United States of America, evaluated 14,000 subjects and the results suggested that Angle's Class II malocclusions occurs in 23% of children. The severity of the malocclusion also correlates with increased dissatisfaction towards dental appearance.[4] It has been estimated that one-third to one-half of clinical orthodontic practices consist of Class II malocclusions.[3] Thus, the etiology, diagnosis, and treatment of Class II malocclusions are of vital importance to practicing orthodontists.

Malocclusion is not a disease, but a variation in morphology that may or may not be associated with a pathological condition.[1] It has been shown that many factors play a role in the development of a Class II malocclusion, including genetics and habits.[5] An Angle's Class II malocclusion classification may be due to either a dental discrepancy, skeletal discrepancy, or a combination of the two. Clinically, the patient's lower first molars are in disto-occlusion with the upper first molars.[1] In particular, Class II Division 1 malocclusions often present with excess overjet as well. A true skeletal Class II maxillo-mandibular relationship may be attributed to a number of variations, including: mandibular retrognathism, maxillary protrusion, increased length of the anterior cranial base, vertical dysplasia, or a combination thereof. Individuals with a Class II malocclusion often present with a convex profile as well.[6,7]

With the large range of clinical features and etiology of Class II malocclusions, the need for an accurate assessment of the sagittal relationship of the mandible to the maxilla is important for accurate diagnosis and treatment planning. Numerous analyses have been created in an attempt to determine the extent of the anteroposterior skeletal discrepancy between the upper and lower jaw.

Downs[8] had first introduced the A-B plane angle to determine the sagittal relationship between the two jaws. Following Downs' work, Riedel[9] introduced the SNA, SNB, and ANB angles. The ANB angle, taken from the difference between SNA and SNB angles, remains the most commonly used measurement today to determine the discrepancy between the maxilla and mandible.[10] However, because ANB is an angle, it can be affected by a number of factors, which in turn can result in a misleading interpretation of the result.[11] Hussels and Nanda[12] found that changes in vertical length, from Nasion to point B, and point A to point B, influenced the ANB angle. In addition, Roth[13] and Chang[14] found that the rotation of the SN line, rotation of the jaws, occlusal plane rotation, and the degree of facial prognathism were all factors in altering the ANB angle.

Jacobson[11,15] believed that a linear measurement was the answer to these problems. In his "Wits Analysis", he drew perpendicular lines from points A and B to the functional occlusal plane. The functional occlusal plane was a plane derived from a line bisecting the overlap of the cusp tips of the maxillary and mandibular molars and premolars. The distance between the two points on the functional occlusal plane would serve as an indicator for the severity of the Class II skeletal discrepancy. He believed this measurement would be less affected by normal variations in cranial structures and would produce a more accurate measurement of the maxillary-mandibular jaw discrepancy. However, the challenges with the Wits analysis became apparent as researchers began using it.

Rushton et al.[16] found that the overlap between the upper and lower dentition resulted in difficulty in identifying the plane. Reproducibility of the landmarks is difficult and they found that this can result in a significant cant of three degrees when the same researcher retraced the cephalometric radiographs. A change in cant of this plane can result in a change of the position of A point and B point onto this plane.[17] This results in a linear difference between the two points (Figure 1). Chang[18] also found that the Wits appraisal is easily affected by the vertical dimension of the jaws. Furthermore, challenges can arise when the patient has a mixed dentition or if the premolars are not fully erupted. The functional occlusal plane is easily affected by tooth eruption or vertical development of the alveolar process.[19] Also, rotation of the functional occlusal plane was shown by Sherman and Woods[20] not to be well correlated with rotation of the jaws during treatment or growth. Harvold[21] found that the rotational growth change that occurred in the jaws was not mimicked by the functional occlusal plane. Thus, a large downfall of the analysis was that a dental parameter was being used to measure a skeletal discrepancy.

Other methods have been created by authors and researchers in an attempt to evaluate the sagittal base relationship between the maxilla and mandible. Freeman[22] created a method to assess the sagittal relationship of the upper and lower jaw that removed the point Nasion. He used the Frankfort horizontal plane instead of the occlusal plane and projected point A perpendicular to this plane and called this point "X" (Fig 2). He then used the angle AXB to determine the sagittal relationship of the maxilla to the mandible. However, Chang[14] showed that the vertical positioning of point B may alter the AXB angle and does not exclusively describe the anteroposterior jaw relationship. Chang[14] suggested an alternative method by projecting points A and B perpendicular to the Frankfort plane, points AF and BF, and assessing the linear measurement between the two points. However, once again, the inaccuracies of Nasion were eliminated, but the measurement did not depict the rotational effect of the jaws during growth and treatment.

The Pi analysis[23] is a recent anteroposterior jaw relationship analysis that tried to incorporate the rotational effect of the jaws during growth and treatment. It consists of the variables Pi angle and the Pi linear, and the maxilla and mandible are represented by skeletal landmarks G and M points, respectively (Fig 3). M point is the centre point of a circle placed at the tangent to the anterior, superior and palatal surfaces of the premaxilla. G point is the centre point of a circle placed at the internal anterior, inferior, and posterior surfaces of the mandibular symphysis. The true horizontal plane, a perpendicular line to the true vertical line, is utilized through Nasion point as the reference plane. G' point and M' point are created by taking a perpendicular line from the G point and M point, respectively, to intersect the true horizontal plane. The points G'G and G'M are then connected and form the Pi angle. The Pi linear is the measurement difference between G' and M'. However, it was found that the Pi measurements were affected by the vertical position of Nasion.[23] Moreover, a weak, non-significant correlation was found between the Pi measurements to various measures of anteroposterior discrepancy.[23] These included the ANB angle and Wits measurement to the functional occlusal plane. No studies have been conducted on the effects of growth on the Pi measurements.

Hall-Scott[24] proposed the use of a new Wits reference plane instead of the functional occlusal plane. Hall-Scott proposed using the maxillo-mandibular bisector (MMB) which was created by bisecting the angle formed from the intersection of the palatal and mandibular planes. The author advocated that this plane was more easily identifiable than the functional occlusal plane and whose rotation would mimic that of the skeletal jaws. She concluded that the MMB was more accurate and had greater correlation with the ANB angle than when compared to the Wits measurements onto the occlusal plane. Furthermore, Foley et al.[25] concluded that the MMB is an effective tool to assess skeletal changes that occur in the treatment of Class II Division 1 cases.

However, it has been discussed that the palatal plane inclination can be variable and is influenced by the patient's facial type.[26,27] This variability in inclination may result in inaccurate readings when using the MMB plane.[28] It has also been shown that the palatal plane inclination can be altered with Class II orthodontic mechanics.[29] Klein[30] found that the palatal plane may sometimes descend more posteriorly than anteriorly in some growers, and in others may not tip down anteriorly. On the other hand, the Frankfort horizontal plane was shown to be the most stable reference plane for cephalometric orientation and growth prediction by Rickets[31]. Furthermore, Chang[18] demonstrated that the Frankfort horizontal plane showed little variation in inclination with growth. Thus, Swoboda et al.[28] proposed using this stable cranial reference line to the mandibular plane, the Frankfort horizontal – mandibular plane bisector (FMAB). Swoboda et al.[28] studied the FMAB on a sample of Class I individuals and concluded that the FMAB was a valid indicator of the anteroposterior skeletal discrepancy and mirrored the changes that were seen using ANB. Furthermore, a good correlation was found between MMB-Wits and FMAB-Wits appraisal, and fewer outliers found using FMAB than when using MMB.

Studies of Class II Division 1 individuals have shown that the dentofacial relationships of these individuals can vary significantly from one another.[32] Therefore, no single treatment modality is suitable for every patient. A number of treatment modalities have been created for the treatment of Class II malocclusions. These include orthopedic growth modification through the use of functional appliances, orthodontic camouflage, and orthognathic surgery. Orthognathic surgery, often involving advancement of the mandible, is an excellent choice in the non-growing patient with a severe maxillo-mandibular discrepancy.[1] In growing patients, orthopedic growth modification is often successful in modifying the patient's growth pattern and correcting the Class II malocclusion.[1] Moreover, orthodontic camouflage through dental movements, in addition to growth modification, can provide an excellent result in correcting Class II malocclusions.

One such approach of correcting a Class II malocclusion, through growth modification with orthodontic camouflage, is the use of headgear and Class II elastics in the growing patient. Extraoral force applied to the maxillary denture has been utilized for many years to correct anteroposterior relationships of the jaws and teeth.[33-36] Depending on the set-up of the headgear, the vector of retraction can be cervical, high-pull, or straight. Cervical headgear has shown to be effective in maxillary molar distalization and for maxillary growth restriction.[37] Studies have reported on the effects of cervical and straight-pull headgear and have shown: i) tipping of the palatal plane downward anteriorly; ii) decrease in the ANB angle; and iii) extrusion of the maxillary first molars.[38,39] However, the vertical claims have been debated. It has been postulated that extrusion of the maxillary molars may result in downward and backward rotation of the mandible, resulting in an increase in the mandibular plane angle.[38] Other studies have shown little effect on the mandibular plane angle when using cervical headgear compared to a control sample.[40]

The use of intermaxillary Class II elastics is used in conjunction with headgear therapy to achieve an ideal result. The use of elastics, which often connect the lower first molar to the upper cuspid, works in conjunction with headgear to correct the dentition into a Class I occlusion.[1] Furthermore, intermaxillary elastics have been demonstrated to primarily move the lower dentition anteriorly, with a slight retraction of the maxillary dentition.[41] Studies in adults have shown that the use of Class II elastics can extrude mandibular molars and increase the mandibular plane angle in these patients.[42] Other studies have revealed that this increase in the mandibular plane angle to be negligible long term in growing patients.[43]

This investigation is intended to evaluate the Frankfort Mandibular Angle Bisector (FMAB) in the assessment of anteroposterior jaw relationships in a sample of Class II malocclusions. The FMAB is the bisector of the angle formed by the Frankfort Horizontal (FH, porion to orbitale) and the mandibular plane (gonion to menton), to which a Wits analysis is performed by projecting points A and B perpendicularly to the bisector and measuring the distance between them (Fig 4).

Specifically, the purposes of this study are to:

1. Evaluate age- and treatment-related changes in sagittal jaw relationship over a sufficiently large time interval from pre-pubertal through puberty (at ages 12, 14, 16 years) using the Frankfort-mandibular bisector (FMAB) Wits, ANB and the maxilla-mandibular bisector (MMB) Wits in both males and females with Class II malocclusions, and compare the reproducibility and variability between these measures;
2. Evaluate changes between individuals with Class II malocclusion treated with headgear and Class II elastics, and control groups to determine changes due to treatment;
3. Determine how the measure FMAB-Wits correlates with the MMB-Wits and the well-established measure ANB in a Class II sample; and

Compare these results to the findings from Swoboda et al.[28] FMAB study with a Class I malocclusion study sample.

Materials and Methods

This study is a retrospective longitudinal study. A sample of 76 Class II Division 1 orthodontically treated subjects (40 female, 36 male) and 30 control subjects (15 female, 15 male) comprised the total study sample. Records for the control group were derived from the Burlington Growth Centre, located at the Faculty of Dentistry, University of Toronto in Toronto, Canada. Records for the treatment group were derived from the Western University Graduate Orthodontic Clinic in London, Ontario, Canada. The age groups utilized in this study for the control sample consisted of age 12 years (T0), age 14 years (T1), and age 16 years (T2). Full records included serial lateral cephalograms and dental casts taken at pre-treatment [T0], immediately after treatment was completed [T1], and at two years post-treatment [T2]. These times corresponded approximately to ages 12, 14, and 16 years, respectively.

The treatment group consisted of subjects who had undergone treatment with fixed appliances, cervical or straight-pull headgear, and Class II elastics. The control group consisted of comparable untreated Class II Division 1 malocclusion individuals in order to compare for normal changes due to growth.

The following pre-treatment inclusion criteria were used for sample collection:

1) No congenitally missing or extracted teeth (except third molars)
2) No craniofacial abnormalities or syndromes
3) Class II skeletal relationship with pretreatment ANB angle greater than 4 degrees
4) Class II Division 1 pre-treatment molar relationship of at least 3.0mm (half cusp) Class II as measured on the corresponding dental cast
5) Overjet greater than 4.0mm
6) Minimal crowding of less than 4.0mm
7) Good quality radiographs

Additional inclusion criteria for the treatment group included:

1) Non-extraction orthodontic treatment with full fixed appliances
2) Either cervical or straight-pull headgear initiated at the beginning of treatment

3) Use of Class II elastics from the maxillary anterior segment to the mandibular posterior segment
4) Non-surgical treatment
5) Class I post-treatment occlusion obtained
6) Passive retention using either a fixed lingual retainer, removable Hawley or Essix retainer

Subjects that did not fulfill the inclusion criteria were excluded from the study, including subjects with previous orthodontic treatment, orthognathic surgery, functional orthopedic appliances, and active retainers.

*G*Power Software Version 3* (Dusseldorf University, Dusseldorf, Germany) was used to calculate the desired sample size for this study, using an alpha value of 0.05, and desired power of 80%. Calculations from the mean and standard deviation values of the FMAB-Wits measurements from the treated sample of Swoboda et al.[28] were used to determine the number of subjects per group. 34 subjects per group were needed to determine a significant difference between T0 and T1 and 14 subjects per group were needed to determine a significant difference between T0 and T2. The control subjects failed to meet the required sample size between T0 and T1 due to limitations of available subjects that met the inclusion criteria from the Burlington Growth Centre.

Cephalometric Methods

Each treatment cephalogram was scanned with an *Epson Scanner* (Epson, Shinjuku, Tokyo). A custom cephalometric analysis was created using *Dolphin Imaging Software, Version 12* (Dolphin Imaging, Chatsworth, CA, USA) and all cephalograms in this study were digitally traced using *the Dolphin software* (Dolphin Imaging, Chatsworth, CA, USA) by the same researcher (HSS). The radiographic enlargement of the cephalometric data from the Burlington Growth Centre is 9.84%. The radiographic enlargement of the cephalometric data from the Western University Orthodontic Clinic is 8.0% for any cephalograms taken prior to 2007, and 9.5% after January 1, 2007, due to a change in imaging hardware. The difference in enlargement of radiographs was calibrated using the *Dolphin Imaging Software* (Dolphin Imaging, Chatsworth, CA, USA), by rendering all images to 8% magnification. The cephalometric analysis consisted of measurements from the analysis of Swoboda et al.[28], consisting of nine landmarks, three cephalometric angles, and two linear measurements. Descriptions of the landmarks, planes, angular measures, and linear measures are shown in Appendix I and II.

Statistical Methods

An error study was performed to assess measurement errors in tracing and digitizing. A complex computer algorithm (http://www.random.org) was used to generate a string of 20 random numbers ranging from 1 to 126. The random numbers corresponded to one of the patients in the sample group of 126 patients. Each patient had all three time points re-traced and re-measured, resulting in 60 repeated tracings. Re-tracings were completed thirty days after the last cephalometric radiograph was traced. Dahlberg's formula was then used to quantify the measurement error for each desired measurement, using the formula: $\sqrt{(\Sigma d^2/2N)}$, where d is the difference between the first and second measure, and N is the sample size that was re-measured.

The reproducibility of measurement (R) was calculated to assess the reliability of the measurement values with the formula: $R=[S^2x-(S^2e/2)]/S^2x$, where S^2x is the variance of the first set of measurements, and S^2e is the variance of the difference between the initial and repeated measurements.

Data was input into *SPSS Version 20.0* (IBM Corporation, Armonk, NY, USA) statistical software program to calculate and confirm descriptive statistics.

An independent-samples t-test ($p < 0.05$) was used to determine if a difference existed between the mean ages of the control and treatment group, between the ages of males and females in the treatment group, and for each cephalometric measure between the control and treatment group. Prior to analyzing the data with an independent-samples t-test, both groups were checked for the presence of significant outliers by assessing boxplots of the data. There were no extreme outliers in the data, as assessed by inspection of a boxplot for values greater than three box-lengths from the edge of the box. For every other outlier detected, an independent-samples t-test was run with and without the outlier in the analysis. The results of the two t-tests were compared and, given the sample size, it was found that each outlier did not have a significant impact on the conclusion drawn.

Normality in the data was assessed using the Shapiro-Wilk test. If the assumption of normality was violated ($p < 0.05$), the data was deemed not normally distributed. A Mann-Whitney U test was used for data that was not normally distributed to determine a difference between the two groups of interest. The distribution of scores was established through visual inspection before running the Mann-Whitney U test.

To test for homogeneity of variances, "Levene's Test for Equality of Variances" was used. There was homogeneity of variances for all scores measured, except for the age group of the control sample. In this case, the assumption of homogeneity of variances was violated and a Welch t-test was used instead.

A Repeated Measures ANOVA was used to determine the presence of any statistically significant differences between the mean values of the different time points within the treatment and control groups, the mean values between males and females within these groups, and the mean values between males and females in the treatment group. To determine statistical significance in pairwise comparisons, Bonferroni *post hoc* tests were used. Outliers were checked and all outliers were kept as they were deemed to have a non-significant impact on the conclusion drawn. Normality was checked with the Shapiro-Wilk test and a non-parametric test, the Friedman test, was used for data that was not normally distributed. Sphericity, the variances of the differences between all combinations of levels of the within-subjects factor, was assessed for violation by running "Mauchly's test of sphericity". The Greenhouse-Geisser adjustment for bias was utilized in data that violated sphericity.

Pearson product-moment correlation coefficients were calculated to measure the relationship between the ANB angle, MMB-Wits and FMAB-Wits in each time period in the treatment and control group.

Results

The measurement error and reproducibility of the repeated measures in this study sample are presented in Table 1. All measurement errors were within acceptable limits and ranged from 0.36° to 1.15° for the angular measurements and 0.49 mm to 0.60 mm for the linear measurements. The reproducibility for all the values were greater than 0.9, indicating a good reproducibility.

The mean ages for the subjects are shown in Table 2 and divided into the treatment and control group. The difference in ages between the two groups is also shown. A significant difference was only found at the T2 time period between the two periods. Table 3 displays the mean ages for each time period for males and females in the treatment group. A significant difference was found in each time period. On average, females with Class II malocclusions began treatment just over nine months earlier than males.

Tables 4 displays the descriptive statistics for each cephalometric variable measured in the control and treatment group at pre-treatment (T0), immediate post-treatment (T1), and at two-year post-retention (T2). Table 5 presents the mean change seen between each time period for the treatment and control groups. For the subtraction of means, the first time period is subtracted from the second time period, so that a negative integer indicates the value decreased from the first time period to the second time period. Table 6 displays the difference between the two groups and the significance detected, with a positive difference indicating a larger value in the treatment group and vice versa for a negative difference. A significant difference ($p < 0.05$) was found in each variable at each time period, except for the Frankfort-Mandibular plane angle (FMA). The treatment group was shown to begin treatment with statistically significantly larger Class II malocclusions than the control group, as seen with the larger ANB, MMB-Wits, and FMAB-Wits scores. At the completion of treatment and at the two-year retention check, the treatment group displayed a significantly less Class II malocclusion than the control sample, as well as a larger MM angle. This is attributed to the correction of the Class II malocclusion through treatment.

Males and females were then divided for the control and treatment group in Tables 7 and 8 with their corresponding mean values. The differences in the treatment group between males and females is shown in Table 11, with positive values indicating a larger value in the male group and negative values indicating a larger value in the female group. All angular measures were less than 1.06 degrees different in each time period between males and females, and less than 1.37mm in the linear measures. Independent t-sample tests indicated no significant differences in all of the variables measured.

The differences *between* each time period were then calculated for each cephalometric variable of interest. Positive values indicate an increase in the value from the initial time period to the next time period. Conversely, a negative value indicates a decrease in value from the initial time period to the next time period. Table 5 shows the change in both males and females in the control and treatment groups. In the control group, a small decrease in the ANB, MMB-Wits, and FMAB-Wits can be seen from ages 12 to 14 and ages 12 to 16. However, these numbers were not statistically significant. A trend of slightly decreasing values is seen in the MMA and FMA measures from age 12 to age 16. Statistical significance is only seen in the MMA from age 12 to 14 and age 12 to 16, as well as FMA from age 12 to 16 ($p < 0.05$). In the treatment group, all values decreased from the initial time period to the two-year post-treatment time period, except for a very small increase in value for FMA from initial time period to immediate completion of treatment. In general, all measurements except for the maxillo-mandibular and Frankfort-mandibular plane angles showed statistical significance ($p < 0.01$).

Males and females were then separated for the control and treatment groups and analyzed separately in Tables 9 and 10. Table 9 shows that males in the control group had extremely small decreases in the anteroposterior measures of ANB, MMB-Wits, and FMAB-Wits from ages 12 to 16. Statistically significant ($p < 0.05$) decreases were seen in the FMA and MMA from initial time period to two-year post retention. In the treatment group, statistically significant ($p < 0.01$) decreases in ANB, MMB-Wits, and FMAB-Wits were seen in all three time period differences. The FMA between T0-T1 was the only measurement seen to have a small increase in value, however this was not statistically significant.

Analysis of the females in Table 10 shows a similar trend that was seen with the males. The control group of females saw small decreases in all values measured across all time differences, however, none were deemed statistically significant. In the treatment group of females, all values again decreased from the initial time period through to the two-year post-retention time period. The ANB, MMB-Wits, and FMAB-Wits showed a statistical and clinical significant decrease ($p < 0.01$) from initial time period to immediate post-treatment and from initial time period to two-year post retention time period.

The differences in the amount of change between males versus females were then analyzed through an independent t-test in Table 12. In the treatment group, the males demonstrated a larger change between time periods than the female groups. A statistically larger decrease was only seen in the ANB angle from immediate post-treatment to two-year post retention (T1-T2) and in the decrease of the FMA during the same time period.

Table 13 displays the Pearson correlation coefficients within the time periods for the control and treatment groups. Using Cohen's suggestions with Pearson correlation coefficients, ANB displayed a moderate, statistically significant ($p < 0.01$) correlation between MMB-Wits and FMAB-Wits in both the control and treatment groups, ranging in value from 0.54 to 0.63. The ANB showed the best correlation with the FMAB-Wits, with a coefficient value of 0.67 in the two-year retention period in the control group. The ANB angle correlated better with the FMAB-Wits across both groups and all time periods compared to the MMB-Wits. The highest correlation values were between MMB-Wits and FMAB-Wits, with all coefficients larger than 0.80. Other correlations were generally low, with the exception of MMA-FMA with Pearson correlation values greater than 0.64.

Discussion

The relationship of the maxilla to the mandible is a crucial component in the diagnosis and successful treatment of Class II malocclusions. Traditionally, reference points in the cranial base have been used to determine the extent of disharmony between the maxilla and mandible during growth.[8,9] The most common measurement, still used today, is the ANB angle. However, it has been found that ANB is subject to variation due to the fact that Nasion is not a point that remains fixed and any change in its position may alter the measured ANB value.[11,15] Enlow has shown that Nasion often moves superior and anterior with growth.[44]

The Wits analysis was created by Jacobson[11] in an attempt to eliminate these errors and still allow assessment of apical base disharmonies without the use of cranial landmarks. However, it was later found that using the functional occlusal plane as a reference plane also introduced difficulty in analysis. The cant of the functional occlusal plane (FOP) altered the measured reading significantly, often giving an extreme value even when an extreme discrepancy did not exist.[19] Richardson[45] noted that any angulation differences, even as little as three degrees, can have a significant impact on the readings for the FOP-Wits measurement.

Researchers deemed that the functional occlusal plane was not easy to identify and varied greatly due to dental eruption.[17,46] Thus, it is important that any cephalometric analysis contain reliable landmarks, angles, and associated planes. Previous findings have noted that the functional occlusal plane contained the largest errors in landmark location.[47] Furthermore, Rotberg et al.[48] noted that there was only a weak correlation between FOP-Wits and ANB, where ANB could only predict the value of FOP-Wits with 38% accuracy.

A number of recommendations have been reported with the goal of improving the Wits analysis.[13,14,17,19,22,25,47] These studies have attempted to account for the skeletal variation in the individual or to change the reference plane with which to project A point and B point. Hall-Scott discussed how the MMB-Wits measurement had less than one-third the measurement error found with the FOP-Wits measurement.[17]

In the present study, the FMAB-Wits measurement was assessed as a valid measure for anteroposterior measurement. Repeat tracing of 60 cephalograms designed to test the reliability of the variables found that the FMAB-Wits had a measurement error of 0.49mm, which was slightly lower than the MMB-Wits error measurement of 0.60mm. Moreover, the reproducibility of the FMAB-Wits was slightly higher than the MMB-Wits, but both were excellent with an $R > 0.90$. This corroborates findings reported by Swoboda et al.[28] in a study of FMAB-Wits in a Class I study sample. The MMB-Wits in previous studies found very low measurement errors as well, indicating the plane is reliable.[17,25]

The ages of the patients in the control and treatment group were compared and a significant difference was only seen at T2 between the two groups (Table 2). This difference is explained by the fact that initial ages were chosen on specific criteria, but the final time period for the treatment group was based on the length of treatment, and not the age of the patient. Conversely, the ages of the control sample were chosen specifically on age only. The treatment group was then divided into males and females (Table 3). The control group was not tested for differences since all of the ages corresponded with a certain age in each time period due to the inclusion criteria requiring the control group meet this age. A significantly older age in each time period in the males was found when compared to the females in the treatment group. On average, males began treatment nine months later than females. This is consistent with the maturation process of males versus females, as females undergo puberty earlier than males.[1,6,44] Ideally, Class II treatment with headgear should begin immediately prior to the patient's pubertal growth spurt, which on average occurs about one year later in males than females.[6] The treatment sample in this study indicated that males, in general, began treatment in accordance with a later growth spurt than females.

A method to evaluate the validity of the FMAB-Wits measurement is to establish how well it correlates with the ANB angle compared to the MMB-Wits measurement. Hall-

Scott[17] found that the ANB angle had a correlation coefficient of r = 0.95 with the MMB-Wits in her study sample of Class II Division 1 individuals. Foley et al.[25] found correlation coefficients ranging from r = 0.35 to r = 0.71 of MMB-Wits with ANB for their Class II Division 1 malocclusion sample. Palleck et al.[49] found a similar range of correlation coefficients between the respective two measurements in a sample of Class I individuals. Conversely, Swoboda et al.[28] found a smaller correlation between ANB angle and the MMB-Wits measurement with correlation coefficient ranging from r = 0.19 to r = 0.51. This may have been due to a large number of outliers that were identified with the palatal plane in that study.

The Pearson correlation analysis in this study showed that the MMB-Wits analysis had a moderate correlation with ANB consistent with other Class II Division 1 sample studies.[17,25,49] These correlation coefficients ranged from r = 0.54 to r = 0.59. The FMAB-Wits measurement overall showed the best correlation with the ANB angle throughout all groups in all time periods. The highest correlations with ANB were with FMAB-Wits at time T2 (r = 0.67), and ranged from r = 0.59 to r = 0.67. The strongest correlations were seen between FMAB-Wits and MMB-Wits, with all values in all time periods for the control and treatment group having an r > 0.8. This strong correlation indicates that these pairs may be used interchangeably in the assessment of anteroposterior jaw relationships.[50] All other correlations showed a generally low correlation factor, with the only other correlation factor greater than 0.6 being MMA-FMA. Since the ANB and the Wits appraisal both describe the anteroposterior relationship of the maxilla to the mandible, a moderate correlation is to be anticipated. However, as each measurement includes a plane or points that are influenced by different variables; a strong correlation between the angular and linear measurements cannot be expected. The correlation between FMAB-Wits and ANB in this study displayed a larger correlation than with ANB and FOP-Wits measurements seen in numerous other studies.[25,48,51,52] These studies include Rotberg et al.[48] and Zamora et al.[52] who found a correlation of r = 0.38 and r = 0.24, respectively, for the correlation between ANB and FOP-Wits.

Although there currently is no perfect diagnostic measure to assess anteroposterior relationships, the ANB angle is still considered the gold standard. The ANB was deemed no less reliable than any other cephalometric measurement in the sagittal anteroposterior parameter.[47] Thus, the ANB angle was used for comparison to validate the FMAB-Wits measure.

The mean values with standard deviations for the control and treatment group are depicted in Table 4. Table 5 shows the change between each time period in the control and treatment group. This table ultimately represents the change seen with growth (control group) and with treatment plus growth (treatment group). In the control group, no significant changes are seen between any of the time groups for the anteroposterior measurement of ANB. Adding to the validity of MMB-Wits and FMAB-Wits is that a similar insignificant decrease in their respective values is seen over the same time period. This is consistent with Stahl et al. study on longitudinal changes in an untreated Class II sample group.[7] Researchers found that Class II dentoskeletal disharmony does not tend to self-correct with growth. Furthermore, Bishara et al.[6] also deemed that Class II skeletal individuals will continue to grow and maintain their Class II skeletal discrepancy, with a minimal decrease in ANB from age 12 to age 16 of 0.60 degrees. Table 5 also shows that there was a statistically significant decrease in the MMA and FMA from the initial time period to two-year post retention. Pancherz[53] noted a "tipping down" of the palatal plane of 0.5 degrees over a similar time period. A very small flattening of the mandibular plane was also seen by Bishara et al.[54] in an untreated Class II Division 1 sample group followed over a similar time period.

In contrast, the treatment group showed significant changes in all anteroposterior measurements from the initial time period to immediate post-treatment and two-year post treatment. The ANB angle decreased by 2.55 degrees and a parallel decrease was seen in the MMB-Wits and FMAB-Wits. Treatment was evaluated by comparing the differences in the measurements between the control and treatment groups in Table 6. All measurement differences, except for the FMA, between the two groups were found to be statistically significant. The smallest differences occurred at the beginning of treatment between the two groups. The treatment group subjects, on average, began treatment with a larger ANB, MMB Wits, and FMAB Wits by 0.66 degrees, 1.10 millimeters, and 0.48 millimeters respectively. This may be due to the fact that the control subjects involved in the Burlington Growth Study participated voluntarily and individuals with more severe Class II malocclusions may have chosen to undergo orthodontic treatment. The largest differences were in the two-year post retention period (T2). This is attributed to the treatment effects of the Class II malocclusion correction.

Treatment with cervical or straight-pull headgear and Class II elastics was deemed to have a significant reduction in the ANB angle, which was mimicked by the MMB-Wits and FMAB-Wits measurements by 1.73 degrees, 2.25 millimeters, and 2.99 millimeters respectively. Kopecky and Fishman[55] found that headgear was an effective means in correcting Class II skeletal malocclusions. Furthermore, Kloehn[56] and Hubbard et al.[57] deemed that correction with headgear was achieved by holding the maxillary molar and maxillary skeletal base in place as the mandible and Nasion grew in a forward direction. Short-term and long-term studies found cervical headgear in conjunction with Class II elastics to be an effective treatment regimen for the treatment of Class II malocclusions.[25,29,30,35,39,40,43,55]

The FMA did not show a significant difference between the two groups at any time period. The FMA was the only measurement shown to increase from pre-treatment to immediate post-treatment, although this was not statistically significant. This can be attributed to the extrusive effects of both the headgear and Class II elastics on molars. However, over more time with growth, the FMA was seen to decrease with compensation from ramal growth. These findings are consistent with Hubbard et al.[57], which concluded that the mandibular plane did not change significantly during treatment due to posterior mandibular growth. Other studies found no significant differences in the mandibular plane between treatment and control groups in a Class II Division 1 sample.[58,59] The MMA decreased by 0.32 degrees more in the control group than the treatment group. This is in a slight contrast to the findings by Kirjaivinen et al.[60] in which the palatal plane was found to tip down more anteriorly in individuals treated with cervical headgear. However, Bacetti et al.[61] found in a study comparing headgear and Class II elastics to a Herbst appliance that the headgear with elastics group had an opening of the MMA by

0.5 degrees from pre-treatment to post-treatment. It was postulated prior to this study that the palatal plane changes due to treatment would be significant and varied, thus altering the readings of the MMB-Wits readings. However, the palatal plane was seen to remain relatively constant throughout treatment and the MMB-Wits trends paralleled the ANB trends.

Both control and treatment groups were then separated by gender. Males and females were separated to assess their respective cephalometric measurement means and standard deviations in Tables 7 and 8. Tables 9 and 10 show the mean changes between each time period for males and females, respectively. Both males and females in the control group exhibited no significant change in the ANB angle, MMB-Wits or FMAB-Wits measurements from T0 to T2. This may be due to the small sample size present in the control group, especially after splitting the control group into two groups. Both the males and females showed a decrease in the MMA and FMA for normal growth over the four year span. The males had a statistically significant decrease from T0 to T2 of 1.96 degrees and 1.67 degrees for MMA and FMA, respectively. These findings compare well with previous studies that indicate the mandibular plane and palatal plane remain unchanged or decrease slightly during growth.[7,34,54,57]

For the treatment group, Table 11 examines the difference in the cephalometric measures at each time period between males and females and found no significant differences. In addition, Table 12 highlights the difference between males and females in the amount of change seen between each time period. In the control group, there was no discernible pattern to differentiate males and females, as the differences between the two groups were very small in the anteroposterior measurements. Males did undergo a larger decrease in the MMA and FMA over the four year time span. In the treatment group, both males and females saw parallel changes in the anteroposterior and vertical aspect. Males saw a larger decrease in the ANB, MMAB-Wits and FMAB-Wits measurements from pre-treatment to two-year post treatment. These larger changes are consistent with a later growth spurt seen in males with normal growth. Males also had a larger increase in FMA at immediate post-treatment, but that was followed by a larger decrease than females in FMA over the next two years due to compensatory ramal growth.

The results of this study suggest that cervical and straight-pull headgear with Class II elastics can be an effective method of correcting Class II malocclusions in males and females. Unfortunately, compliance could not be determined in terms of length of headgear wear and elastic wear for each patient. Thus, it is unclear how much correction had been achieved from the headgear and how much from elastics. Nevertheless, a review of the documentation in the chart revealed that the treatment group patients had achieved near Class I occlusion prior to beginning Class II elastic wear. Without intervention, individuals are likely to continue growing in a Class II direction and the skeletal discrepancy will not correct on its own.[7,51,54] The MMAB-Wits and FMAB-Wits measurements mirrored the findings found with the ANB angle. Both the MMA and FMA angular measurements were found to decrease very mildly over time, with or without treatment. A transient increase in the FMA post-treatment was well compensated for by continued ramal growth.

Assessment of the anteroposterior skeletal discrepancy is highly dependent on identifying the correct location of landmarks. Though minimal, the FMAB had a lower measurement error and higher reproducibility than the MMB. Furthermore, the FMAB-Wits measurement correlated better with the ANB angle with a correlation coefficient $r > 0.59$ across both groups and all time periods.

It should be noted that sources of potential error when using cephalometric methods may include difficulty in identifying landmarks from poor radiographic images and individual anatomic variations. No single cephalometric parameter should be relied on entirely when arriving to an appropriate diagnosis and treatment plan as there is large variability among human populations. It should be remembered that not all angular and linear measurements have equal reliability. Using the FMAB-Wits analysis as an adjunct in the assessment of anteroposterior skeletal discrepancy has been shown to be a valid analysis.

Future studies may include comparing the FMAB-Wits appraisal to recent anteroposterior analyses that take into account the rotational effect of the jaws, such as the Pi analysis. Also, further investigations may look at the changes in the FMAB-Wits appraisal in a Class III sample group.

Conclusion

The conclusions that can be derived from this investigation are as follows:

1. The validity of the FMAB-Wits measurement is supported by the fact that it mimics the changes with growth and treatment that are seen in the ANB angle in a Class II sample. The FMAB-Wits had a slightly higher correlation coefficient than the MMB-Wits, further reinforcing its validity.
2. A significant difference in age was found between males and females in the treatment group at all time periods. These results indicate that females generally begin Class II treatment earlier than males, likely due to earlier female skeletal maturation.
3. A good correlation ($r > 0.80$) was found between the MMB-Wits and FMAB-Wits appraisal measurements in both the control and treatment groups for all time periods. This indicates that the use of either of these measures may be interchangeable.
4. Headgear and Class II elastics can be an effective means in correcting a Class II malocclusion, as seen by reduction in the ANB angle, FMAB-Wits, and MMB-Wits measurements.

Table 1: Measurement Error and Reproducibility of Cephalometric Variables (n = 60)

Measure	Measurement Error	Reproducibility
ANB	0.36°	0.97
MMA	1.15°	0.94
FMA	1.08°	0.95
MMB-Wits	0.60 mm	0.93
FMAB-Wits	0.49 mm	0.96

Table 2: Mean Ages at T0, T1 and T2 for the Control and Treatment Groups and the Difference in Each Time Period

(Subtraction of Means: Treatment-Control)

	AGE AT T0 (months)	**AGE AT T1 (months)**	**AGE AT T2 (months)**
	Mean +/- SD	**Mean +/- SD**	**Mean +/- SD**
Treatment	144.75 +/- 10.42	172.24 +/- 12.68	197.46+/-12.71
Control	144.73 +/- 1.08	168.67 +/- 0.96	192.57 +/- 0.86
Difference	0.02 +/- 1.21	3.57 +/- 1.46	4.89 +/- 1.47*

** = $p < 0.05$*

Table 3: Mean Ages at T0, T1, T2 for Males and Females in the Treatment Group and the Difference in Each Time Period

(Subtraction of Means: Males-Females)

TREATMENT GROUP	**AGE AT T0 (months)**	**AGE AT T1 (months)**	**AGE AT T2 (months)**
	Mean +/- SD	**Mean +/- SD**	**Mean +/- SD**
Males	149.58 +/- 9.43	176.81 +/- 11.38	201.53 +/- 11.34
Females	140.40 +/- 9.38	168.12 +/- 12.52	193.80 +/- 12.90
Difference	9.18 +/- 2.16*	8.68 +/- 2.75*	7.73 +/- 2.80*

** = $p < 0.05$*

Table 4: Means and Standard Deviations at Each Time Period in the Control and Treatment Groups

	CONTROL			*TREATMENT*		
	T0	**T1**	**T2**	**T0**	**T1**	**T2**
ANB (°)	5.20 +/- 1.03	5.08 +/- 1.21	5.04 +/- 1.32	5.86 +/- 1.49	3.7 +/- 1.69	3.31 +/- 1.72
MMA (°)	25.36 +/- 4.61	24.48 +/- 4.67	24.06 +/- 4.59	27.93 +/- 4.15	27.59 +/- 4.71	26.95 +/- 4.70
FMA (°)	25.53 +/- 4.35	24.89 +/- 4.6	24.33 +/- 4.59	25.41 +/- 3.82	25.67 +/- 3.98	24.95 +/- 4.15
MMB-Wits (mm)	0.52 +/- 1.54	0.37 +/- 1.54	0.39 +/- 1.61	1.61 +/- 2.07	-1.45 +/- 2.03	-1.85 +/- 2.25
FMAB-Wits (mm)	0.8 +/- 1.92	0.7 +/- 1.94	0.76 +/- 1.87	1.29 +/- 1.68	-1.75 +/- 2.30	-2.24 +/- 2.57

Table 5: Mean Change Between Each Time Period in the Control and Treatment Groups

	CONTROL GROUP			*TREATMENT GROUP*		
	T0-T1	**T1-T2**	**T0-T2**	**T0-T1**	**T1-T2**	**T0-T2**
ANB (°)	-0.11 +/- 0.49	-0.04 +/- 0.46	-0.16 +/- 0.62	-2.16 +/- 1.10^	-0.38 +/- 0.79^	-2.55 +/- 1.17^
MMA (°)	-0.87 +/- 1.62*	-0.43 +/- 1.58	-1.30 +/- 1.93*	-0.34 +/- 2.01	-0.64 +/- 1.67^	-0.98 +/- 2.25^
FMA (°)	-0.63 +/- 1.39	-0.57 +/- 1.47	-1.20 +/- 1.68*	0.24 +/- 2.42	-0.72 +/- 1.94^	-0.47 +/- 2.79^
MMB-Wits (mm)	-0.14 +/- 1.05	0.02 +/- 0.82	-0.12 +/- 1.06	-3.06 +/- 1.83^	-0.40 +/- 1.11^	-3.47 +/- 1.82^
FMAB-Wits (mm)	-0.10 +/- 1.12	0.06 +/- 0.60	-0.04 +/- 1.06	-3.04 +/- 2.00^	-0.48 +/- 1.12^	-3.53 +/- 2.15^

* = *p<0.05*

^ = *p<0.01*

Table 6: Differences Between Treatment and Control Groups (Subtraction of Means: Treatment-Control)

DIFFERENCE *(Treatment - Control)*	**T0**	**T1**	**T2**
ANB (°)	0.66+/- 0.46*	-1.38 +/- 0.48^	-1.73 +/- 0.4^
MMA (°)	2.57 +/- 0.46*	3.10 +/- 0.04^	2.89 +/- 0.12^
FMA (°)	-0.11 +/- 0.54	0.78 +/- 0.62	0.63 +/- 0.44
MMB-Wits (mm)	1.10 +/- 0.53*	-1.82 +/- 0.49^	-2.25 +/- 0.64^
FMAB-Wits (mm)	0.49 +/- 0.24*	-2.45 +/- 0.36^	-2.99 +/- 0.70^

* = *p<0.05*

^ = *p<0.01*

Table 7: Means and Standard Deviations for Males and Females at Each Time Period in the Control Group

CONTROL GROUP	*MALES*			*FEMALES*		
	T0	**T1**	**T2**	**T0**	**T1**	**T2**
ANB (°)	5.19 +/- 1.01	5.29 +/- 1.16	5.18 +/- 1.33	5.2 +/- 1.05	4.87 +/- 1.22	4.9 +/- 1.29
MMA (°)	27.33 +/- 4.28	26.08 +/- 4.81	25.37 +/- 4.71	23.39 +/- 4.06	22.89 +/- 3.91	22.75 +/- 4.06
FMA (°)	27.19 +/- 3.93	26.35 +/- 4.5	25.53 +/- 4.88	23.86 +/- 4.11	23.43 +/- 4.21	23.13 +/- 3.94
MMB-Wits (mm)	0.64 +/- 1.70	0.54 +/- 1.61	0.55 +/- 1.73	0.39 +/- 1.36	0.21 +/- 1.45	0.24 +/- 1.47
FMAB-Wits (mm)	1.06 +/- 2.14	1.23 +/- 2.13	1.16 +/- 1.99	0.53 +/- 1.64	0.16 +/- 1.55	0.35 +/- 1.65

Table 8: Means and Standard Deviations for Males and Females at Each Time Period in the Treatment Group

TREATMENT GROUP	*MALES*			*FEMALES*		
	T0	**T1**	**T2**	**T0**	**T1**	**T2**
ANB (°)	5.9 +/- 1.37	3.7 +/- 1.39	3.15 +/- 1.49	5.82 +/- 1.58	3.7 +/- 1.93	3.46 +/- 1.9
MMA (°)	28.49 +/- 4.04	27.97 +/- 4.44	26.97 +/- 4.6	27.42 +/- 4.18	27.29 +/- 4.92	26.92 +/- 4.8
FMA (°)	25.64 +/- 3.42	26.08 +/- 3.32	24.78 +/- 3.98	25.21 +/- 4.13	25.3 +/- 4.46	25.11 +/- 4.3
MMB-Wits (mm)	1.42 +/- 2.11	-2.08 +/- 1.71	-2.43 +/- 2.12	1.79 +/- 2.02	-0.88 +/- 2.12	-1.34 +/- 2.24
FMAB-Wits (mm)	1.04 +/- 1.89	-2.36 +/- 2.07	-2.96 +/- 2.43	1.51 +/- 1.44	-1.20 +/- 2.35	-1.59 +/- 2.52

Table 9: Mean Change Between Each Time Period in the Control and Treatment Groups for Males

	CONTROL GROUP			*TREATMENT GROUP*		
	T0-T1	**T1-T2**	**T0-T2**	**T0-T1**	**T1-T2**	**T0-T2**
ANB (°)	0.1 +/- 0.35	-0.11 +/- 0.49	-0.01 +/- 0.56	-2.21 +/- 1.20^	-0.55 +/- 0.82^	-2.75 +/- 1.15^
MMA (°)	-1.25 +/- 1.63*	-0.71 +/- 1.94	-1.96 +/- 2.07*	-0.57 +/- 1.83	-0.94 +/- 1.68^	-1.51 +/- 2.23^
FMA (°)	-0.84 +/- 1.26	-0.83 +/- 1.69	-1.67 +/- 1.71*	0.42 +/- 1.72	-1.30 +/- 2.10	-0.88 +/- 2.83^
MMB-Wits (mm)	-0.10 +/- 1.00	0.01 +/- 0.85	-0.09 +/- 0.88	-3.50 +/- 1.99^	-0.35 +/- 1.29^	-3.85 +/- 1.99^
FMAB-Wits (mm)	0.17 +/- 0.70	-0.07 +/- 0.69	-0.10 +/- 0.63	-3.41 +/- 2.03^	-0.59 +/- 1.10^	-4.00 +/- 2.14^

* = *p<0.05*

^ = *p<0.01*

Table 10: Mean Change Between Each Time Period in the Control and Treatment Groups for Females

	CONTROL GROUP			*TREATMENT GROUP*		
	T0-T1	**T1-T2**	**T0-T2**	**T0-T1**	**T1-T2**	**T0-T2**
ANB (°)	-0.33 +/- 0.53	0.03 +/- 0.42	-0.30 +/- 0.65	-2.12 +/- 1.00^	-0.24 +/- 0.73	-2.36 +/- 1.15^
MMA (°)	-0.5 +/- 1.51	-0.14 +/- 1.05	-0.64 +/- 1.52	-0.14 +/- 2.14	-0.37 +/- 1.61	-0.5 +/- 2.16
FMA (°)	-0.43 +/- 1.49	-0.31 +/- 1.15	-0.73 +/- 1.51	0.09 +/- 2.91	-0.20 +/- 1.62	-0.11 +/- 2.70
MMB-Wits (mm)	-0.19 +/- 1.11	0.03 +/- 0.78	-0.15 +/- 1.21	-2.67 +/- 2.25^	-0.46 +/- 0.92	-3.13 +/- 1.58^
FMAB-Wits (mm)	-0.37 +/- 1.37	0.19 +/- 0.46	-0.18 +/- 1.35	-2.71 +/- 1.92^	-0.38 +/- 1.13	-3.10 +/- 2.07^

* = *p<0.05*

^ = *p<0.01*

Table 11: Differences Between Males and Females in the Treatment Group at T0, T1, T2 (Subtraction of Means: Males-Females)

DIFFERENCE IN TREATMENT GROUP			
	T0	**T1**	**T2**
ANB (°)	0.08 +/- 0.34	0.00 +/- 0.39	-0.31 +/- 0.39
MMA (°)	1.06 +/- 0.96	0.63 +/- 1.09	0.05 +/- 1.09
FMA (°)	0.45 +/- 0.88	0.78 +/- 0.92	-0.32 +/- 0.96
MMB-Wits (mm)	-0.37 +/- 0.48	-1.20 +/- 0.45	-1.09 +/- 0.51
FMAB-Wits (mm)	-0.47 +/- 0.39	-1.16 +/- 0.52	-1.37 +/- 0.58

Table 12: Differences in the Mean Change Between Males and Females (Subtraction of Means: Males-Females)

	CONTROL GROUP			*TREATMENT GROUP*		
	T0-T1	**T1-T2**	**T0-T2**	**T0-T1**	**T1-T2**	**T0-T2**
ANB (°)	0.43 +/- 0.17	-0.14 +/- 0.18	0.29 +/- 0.23	-0.08 +/- 0.26	-0.31 +/- 0.18	-0.39 +/- 0.27
MMA (°)	-0.75 +/- 0.59	-0.57 +/- 0.59	-1.32 +/- 0.69	-0.43 +/- 0.46	-0.58 +/- 0.38	-1.01 +/- 0.51
FMA (°)	-0.41 +/- 0.52	-0.52 +/- 0.55	-0.93 +/- 0.61	0.33 +/- 0.56	-1.10 +/- 0.43*	-0.77 +/- 0.64
MMB-Wits (mm)	0.09 +/- 0.40	-0.03 +/- 0.31	0.06 +/- 0.40	-0.83 +/- 0.41	0.11 +/- 0.26	-0.72 +/- 0.42
FMAB-Wits (mm)	0.55 +/- 0.41	-0.27 +/- 0.42	0.28 +/- 0.40	-0.70 +/- 0.46	-0.21 +/- 0.26	-0.91 +/- 0.49

* = *p<0.05*

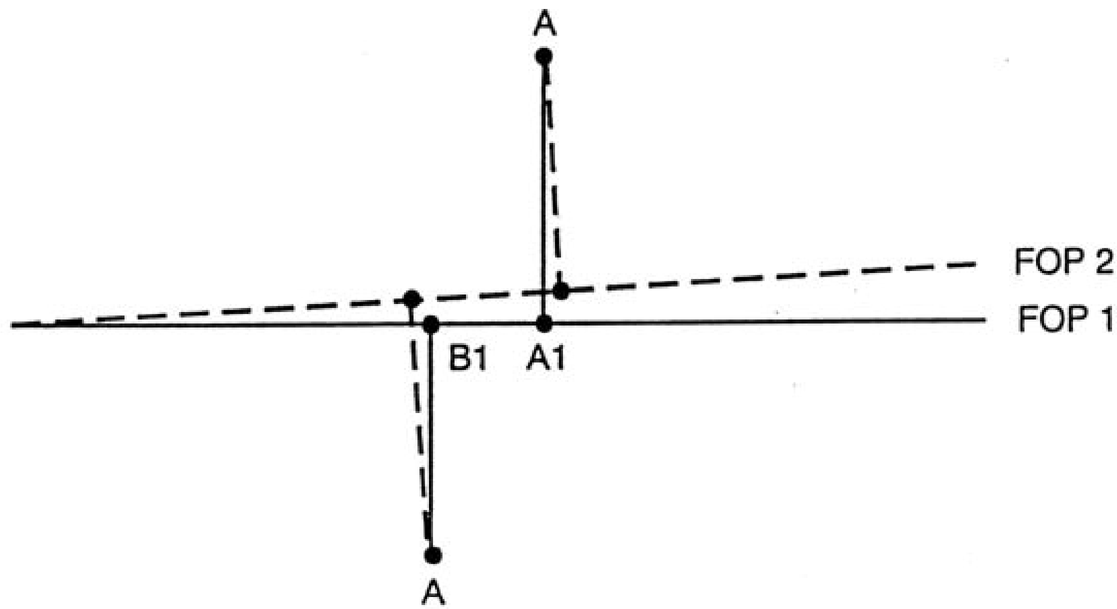
^ = *p<0.01*

Table 13: Pearson Correlation Coefficients Within the Time Periods for the Control and Treatment Groups

	CONTROL			*TREATMENT*		
	T0	**T1**	**T2**	**T0**	**T1**	**T2**
ANB-MMB Wits	0.59^	0.54^	0.63^	0.54^	0.56^	0.59^
ANB-FMAB Wits	0.59^	0.61^	0.67^	0.60^	0.58^	0.63^
MMB Wits - FMAB Wits	0.87^	0.86^	0.80^	0.80^	0.84^	0.86^
FMA-ANB	0.08	0.28	0.36	0.37^	0.50^	0.49^
FMA-MMB Wits	-0.04	0.12	0.26	0.04	0.1	0.04
FMA-FMAB Wits	0.02	0.12	0.19	0.16	0.14	0.08
MMA-ANB	-0.14	0.09	0.13	0.33^	0.37^	0.34^
MMA-MMB Wits	0.05	0.21	0.28	0.19	0.09	0.09
MMA-FMAB Wits	-0.05	0.21	0.19	0.04	0.02	-0.1
MMA - FMA	0.69^	0.68^	0.64^	0.65^	0.78^	0.75^

^ = *p< 0.01*

Fig 1: The Effect of Change in the Cant of the Functional Occlusal Plane on the Measured Wits Value



The distance between the projected points A1 and B1 would be increased as the functional occlusal plane is tilted in a counter-clockwise direction. This increase distance would yield a result that indicated a greater Class II malocclusion, though the positions of A point and B point have not changed.

Referenced from Hall-Scott[17]

Fig 2: AXB Angle, as proposed by Freeman (1981)

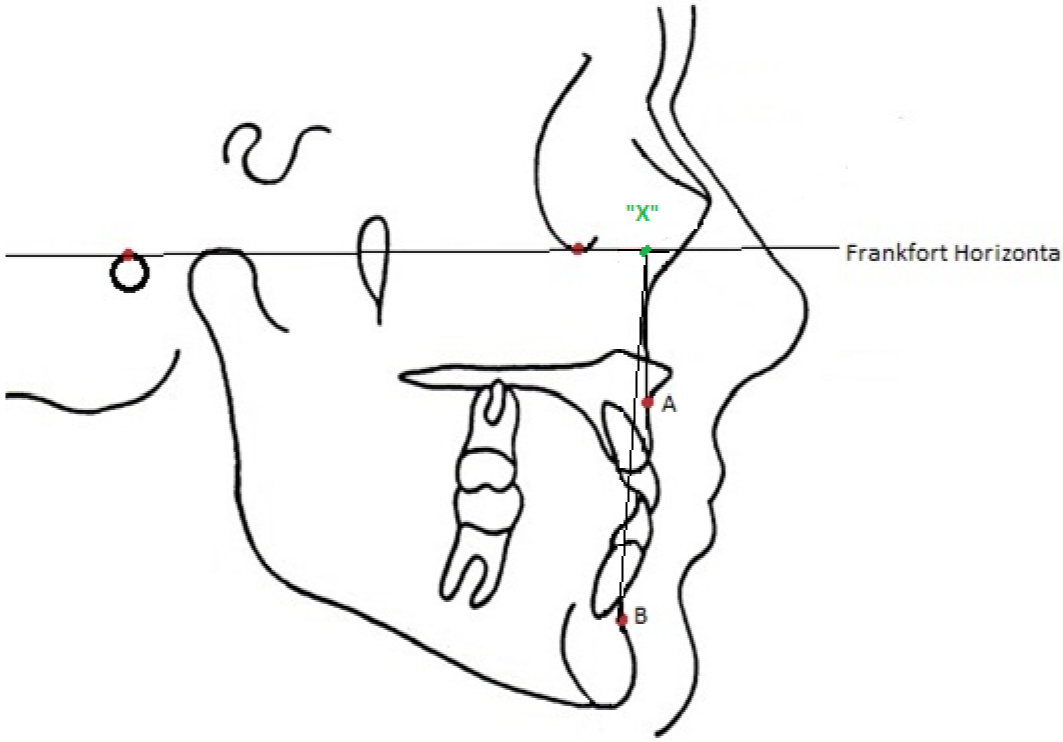
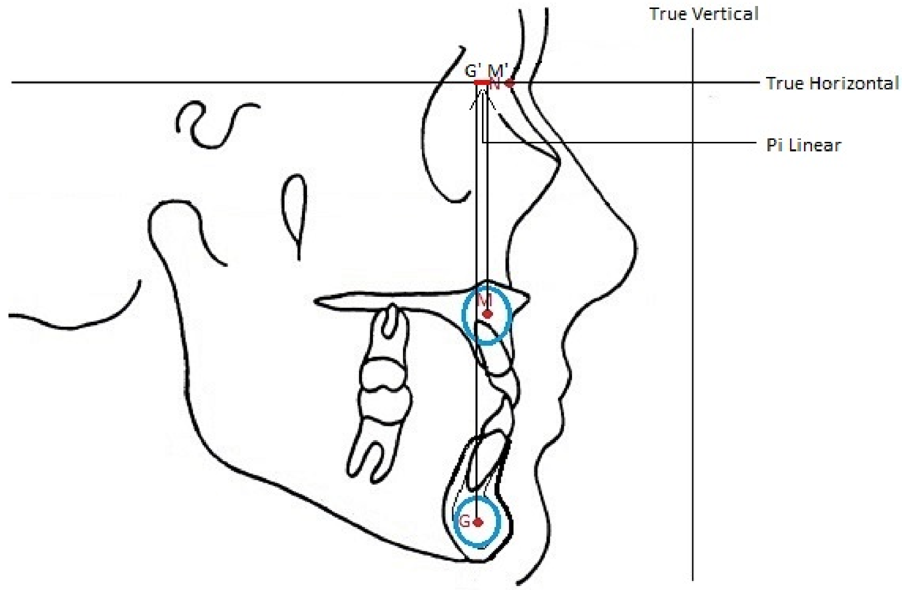
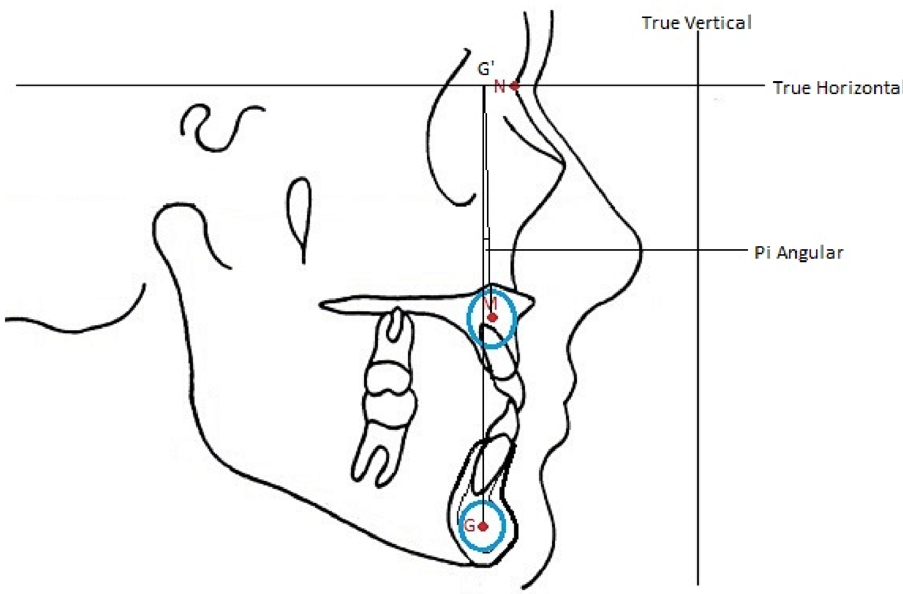


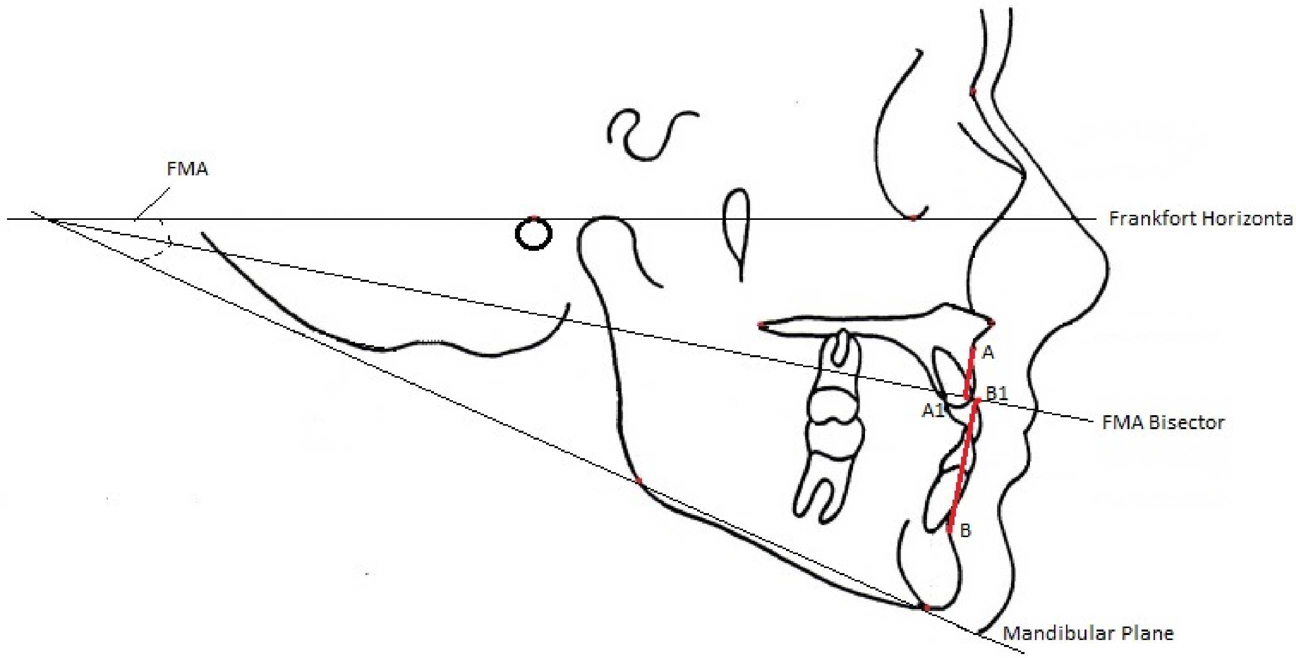
Figure 3: Pi analysis, as proposed by Kumar (2012)





Referenced from Swoboda et al.[28]

Fig 4: The Frankfort Mandibular Plane Bisector (FMAB) Wits Measurement

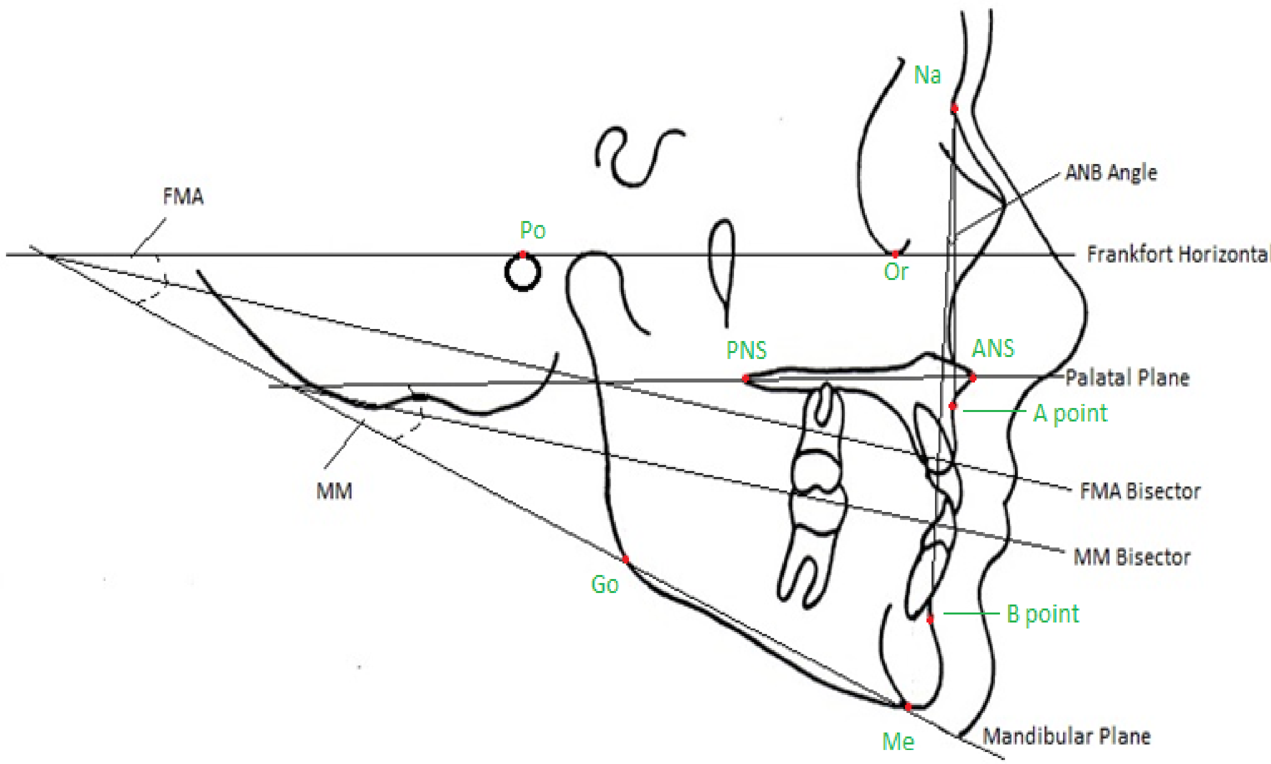


FMAB-Wits Measurement = distance (mm) between A1 and B1

A1 anterior to B1 = Positive integer

A1 posterior to B1 = Negative integer

Fig 5: Cephalometric Measurements Performed



Constructed Cephalometric Points

Point	Definition
A1	A point projected perpendicular to FMAB
B1	B point projected perpendicular to FMAB
A2	A point projected perpendicular to MMB
B2	B point projected perpendicular to MMB

Fig 6: Comparisons of the Mean Cephalometric Measurements at Each Time Period for the <u>Treatment</u> Group

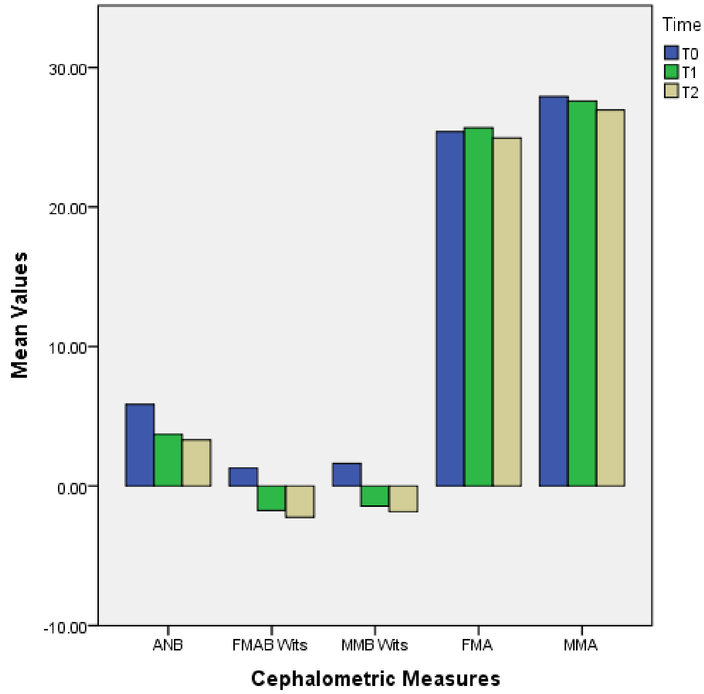


Fig 7: Comparisons of the Mean Cephalometric Measurements at Each Time Period for the <u>Control</u> Group

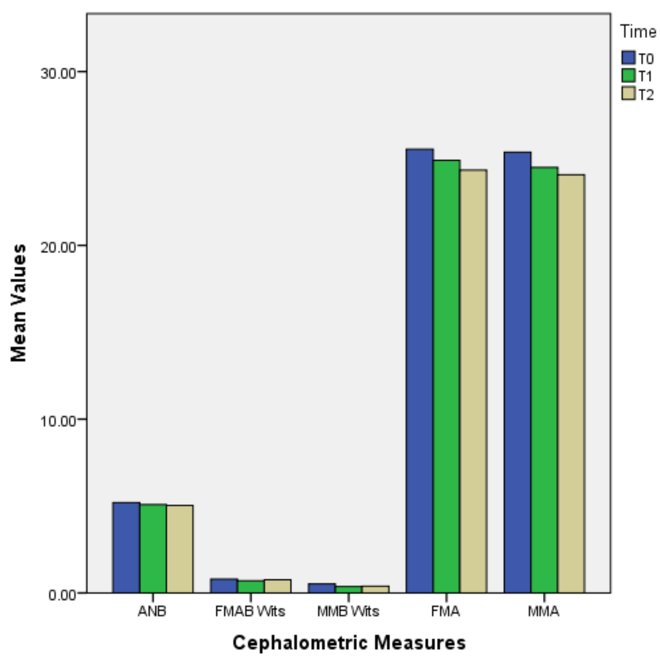


Fig 8: Comparisons of the Mean Cephalometric Measurements at Each Time Period for Males in the Treatment Group

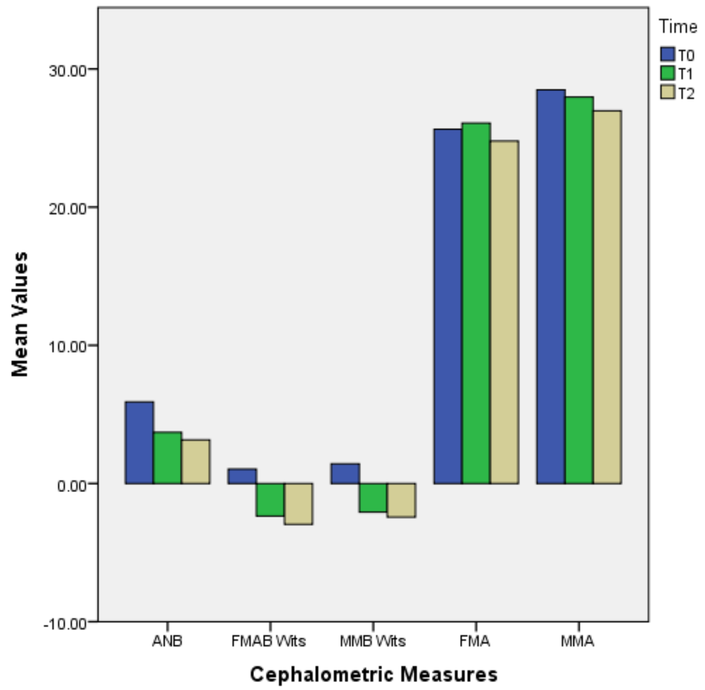


Fig 9: Comparisons of the Mean Cephalometric Measurements at Each Time Period for Males in the Control Group

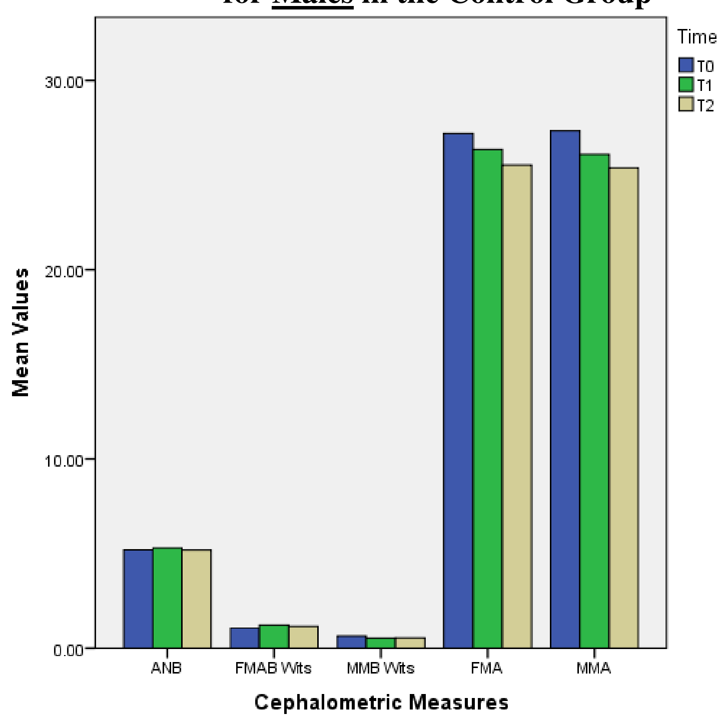


Fig 10: Comparisons of the Mean Cephalometric Measurements at Each Time Period for Females in the Treatment Group

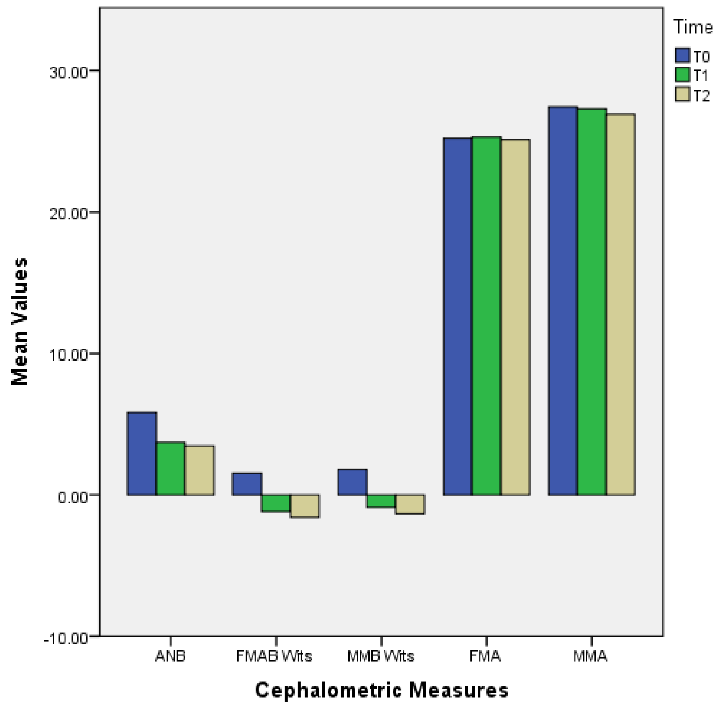
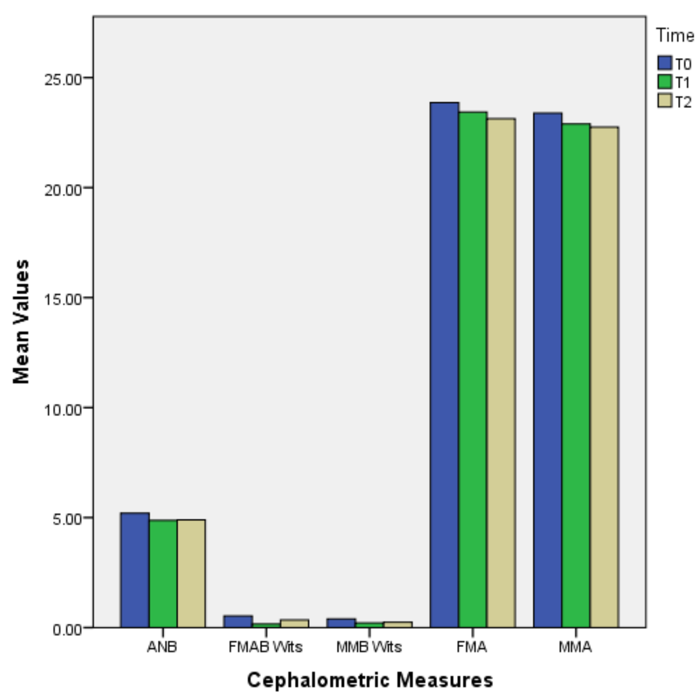


Fig 11: Comparisons of the Mean Cephalometric Measurements at Each Time Period for Females in the Control Group



APPENDIX I

Definition of Cephalometric Landmarks and Planes

Landmark (Abbreviation)	Definition
Porion (Po)	The uppermost margin of the external auditory meatus
Orbitale (Or)	The lower point on the lower margin of the bony orbit
Nasion (Na)	The junction of the frontonasal suture at the most posterior point of the curve at the bridge of the nose
Anterior Nasal Spine (ANS)	The most anterior point on the maxilla at the level of the palate
Posterior Nasal Spine (PNS)	The most posterior point on the maxilla at the level of the bony hard palate
A point (A)	The most posterior point on the curve of the anterior maxilla
B point (B)	The most posterior point on the concave outline of the mandibular symphysis labial to the lower incisors
Menton (Me)	The lower point on the outline of the bony chin
Gonion (Go)	The lowest most posterior point at the angle of the mandible

APPENDIX II

Definition of Cephalometric Planes and Angles

Planes (Abbreviation)	Definition
Frankfort Horizontal (FH)	A line joining Porion and Orbitale
Palatal Plane (PP)	A line joining ANS and PNS
Mandibular Plane (MP)	A line joining Menton and Gonion
Maxillomandibular Bisector Plane (MMB)	The bisector of the maxillomandibular bisector
Frankfort Mandibular Bisector Plane (FMAB)	The bisector of the Frankfort mandibular angle

Angles (Abbreviation)	Definition
ANB Angle (ANB)	The angle formed by the points A point – Nasion – B point
Maxillomandibular Angle (MMA)	The angle formed by the intersection of the palatal plane and mandibular plane
Frankfort Mandibular Angle (FMA)	The angle formed by the intersection of the Frankfort horizontal and the mandibular plane

APPENDIX III

Control Subjects
Burlington Growth Study Computer ID Numbers
(n = 30)

Number	**Gender**
1056	F
288	F
1024	F
170	F
2538	F
847	F
848	F
2601	F
134	F
118	F
1202	F
2588	F
482	F
806	F
494	F
2557	M
849	M
492	M
1312	M
1336	M
897	M
1068	M
1144	M
231	M
1378	M
1306	M
2573	M
1397	M
825	M
2602	M

APPENDIX IV

Treated Subject from Western University Graduate Orthodontic Department
UWO Computer ID Numbers
(n = 76)

Number	Gender
40114	F
20083	F
1082	F
848	F
1993	F
1166	F
3201	F
3202	F
40146	F
20096	F
3210	F
1196	F
1333	F
2923	F
10171	F
50143	F
40080	F
30132	F
30093	F
2800	F
70135	F
1101	F
1104	F
1739	F
50347	F
1118	F
1128	F
20048	F
20159	F
709	F
2522	F
40037	F
838	F
30111	F
1364	F
50064	F

Number	Gender
40070	F
40171	F
30017	F
30006	F
815	M
1367	M
577	M
2147	M
40118	M
40013	M
30048	M
2333	M
2546	M
810	M
108	M
1217	M
1218	M
1012	M
50301	M
50246	M
2794	M
1457	M
479	M
30163	M
30020	M
180	M
40138	M
3307	M
830	M
20090	M
20133	M
1615	M
976	M
981	M
1496	M
746	M
40023	M
1011	M
80006	M
604	M

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